On the Acceleration of Beta Nuclides Decay by the Photonuclear Reaction

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***Abstract*- The present paper develops a model for calculating the rate of photonuclear reaction (beta decay) for nuclear transmutation in the reducing of radioactive waste. A photonuclear reaction is viewed as an incident photon creating superconducting hot spot (hot belt) across a nucleon from the composition of an unstable nuclide (radioisotope), followed by a thermally induced vortex crossing which turns superconducting hot belt into the normal state (vacuum) resulting in a vortex assisted photon beta decay. Because of this model requires data on energies of vortex and on currents from inside of the nucleon, an analog of a superconductor model was developed for the nucleon. Thus, it revisited the dual Ginzburg-Landau model for the calculation of Lorenz force, monopoles current, and the energy of vortex lines for a vortex triangular lattice type Abrikosov within a nucleon to find their meaning. For now, it was found that these energies would correspond to the subatomic particles, W, Z, Higgs bosons, pion π^{+}, and nucleon itself. As check points of this model are considered, the deduction of the fusion temperature of two nucleons, even this model itself for photonuclear reaction mechanism, the explanation of the mechanism of natural beta decay as dark counts and comparison with the results of the IBA nuclide substructure model are also considered. Finally, the model provides counts (decay) rates (R_{pc}), and allows the estimation of intensity R_h ($photons/s$), and of threshold value of photon energy (MeV), in order to achieve $R_{pc}/R_h \cong 1$, or (100%) efficiency. Such efficient installations could be, for example, the laser ELI-NP in construction in Romania for the high energy photon source.**

Keywords-Beta Decay; Nuclear Transmutation; Photonuclear Reactions; High Energy Lasers; W,Z,H Bosons; G-L Theory

I. INTRODUCTION

The Photonuclear reactions are proven to be of potential interest for nuclear transmutation [1] in the handling of radioactive waste, which is a big problem in nuclear energy.

Photonuclear cross sections are quite large (~1 barn) at the giant resonance (GR) region of $E_{\gamma}=15\div 30MeV$. Major $(\gamma,2n)$ and (γ,n) reactions on long-lived nuclei may transmute them to short-lived or stable nuclei.

Till now, the coherent photonuclear isotope transmutation (CPIT) produces exclusively radioactive isotopes (RIs) by coherent photonuclear (y,n) and $(2y,n)$ reactions via E1 giant resonances [1]. Photons to be used are medium energy $E(\gamma)$=12-25[MeV] photons produced by laser photons backscattered off GeV electrons.

The photon intensity of around $10^{8\text{-}12}/s$ is realistic by using intense lasers and intense electrons. In future high intensity photon sources with the intensity of the order of $10^{14\text{-}15}/s$ will be possible. Therefore, there are two conditions for a photonuclear reaction to happen: the intensity, and the threshold energy of photons, respectively.

Otherwise, in [2a] in the frame of nanowire single-photon detector (SNSPD) research, the transition from a current-biased metastable superconducting (s) state to the normal (n) state is triggered by vortices crossing the thin film superconducting strip from one edge to another due to the Lorentz force. Thus, a photon creates a spot which suppresses the order parameter that lowering the energy barrier for vortex crossing.

The model developed in [2a] is based entirely on the Ginsburg-Landau theory of superconductivity.

In the present paper, based on the above models [1, 2a], a photonuclear reaction is viewed as an incident photon creating superconducting hot spot (hot belt) across nucleon from the composition of an unstable nuclide (radioisotope), followed by a thermally induced vortex crossing, which turns superconducting hot belt into the normal state (vacuum) resulting in a vortex assisted photon beta decay.

Since a model requires data on the energies of the vortex and on the currents from inside of the nucleon, an analog of a superconductor model was developed for the nucleon.

Usually, the masses of W, Z are calculated by taking into account and a priori Higgs field, and the default using the Higgs mechanism and Higgs boson.

Soon after the advent of QCD, Hooft and Mandelstam [3] proposed the dual superconductor scenario of confinement; the QCD vacuum is thought to behave analogously to an electrodynamic superconductor but with the roles of electric and magnetic fields being interchanged: a condensate of magnetic monopoles expels electric fields from the vacuum. If one now puts electric charge and anti-charge into this medium, the electric flux that forms between them will be squeezed into a thin, eventually string-like, Abrikosov-Nielsen-Oleson (ANO) vortex which results in linear confinement.

The dual superconductor mechanism [3] is an alternative that does not require the ad hoc introduction of a Higgs field but instead uses dynamically generated topological excitations to provide the screening supercurrents. For example, U (1) lattice gauge theory contains Dirac magnetic monopoles in addition to photons. The dual superconductor hypothesis postulates that these monopoles provide the circulating color magnetic currents that constrain the color electric flux lines into narrow flux tubes. Hooft has shown that objects similar to the Dirac monopoles in U (1) gauge theory can also be found in non-Abelian SU (N) models.

The results are consistent with a dual version of the Ginzburg-Landau model of superconductivity. What is

important in understanding field (magnetic) dependence was Abrikosov's field theoretical approaches based on Ginsburg-Landau theory [4] for type I superconductors ($\kappa \triangleright 1/\sqrt{2}$, $k=\lambda/\xi$, λ is the penetration depth, ξ the coherence length) and type ones ($\kappa \triangleright 1/\sqrt{2}$) II superconductors, which allows magnetic flux Φ to penetrate the superconductor in a regular array quantized in units of elementary flux quantum $\Phi=\pi\hbar c/e$ .The importance was the quantization in a ring , flux $\Phi=\left(n+\frac{1}{2}\right)\frac{\hbar c}{e}, \ (n=0,\pm 1,\cdots)$

In the present paper we revisited G-L model [4, 5, 6, 7, 8, 9, 10, 11, 12, 13] in order to calculate the values of the Lorenz force, the current, and the energies of the Abrikosov vortex lines inside of the nucleon, in natural units, firstly, in view to search for its relevance; for the time being, it was found that this would correspond to energies for subatomic particles, such as that of W,Z , Higgs bosons, and of pion π^+ , and secondarily to be used in the model of vortex-assisted single photon count.

In Section IV the model is applied to formulate the mechanism of natural beta decay as dark count.

In this model to a superconductor analogue, we do not use any a- priori field (Higgs), we use only a comparison with the electrical field generated by the pair (dipole) $q\overline{q}$.

If these kinds of predictions continue to be verified by appropriate experiments, one may have a cheap solution to remove the radioactive waste of used-up nuclear fuel rods of fission reactors in a reasonable time period.

II. DESCRIPTION OF THE ANALOGUE MODEL OF NUCLEON TO A SUPERCONDUCTOR

The normal cores that exist in type-II superconductors in the mixed state are not sharply delineated. The value of number density of superelectrons n_s is zero at the center of the cores and rises over a characteristic distance ξ , the coherence length. The magnetic field associated with each normal core is spread over a region with a diameter of 2λ, and each normal core is surrounded by a vortex of circulating current.

The QCD vacuum can be viewed as a dual superconductor characterized by a monopole condensate [3, 9, 11], when embedding a static $q\overline{q}$ pair into the vacuum. The core of the flux tube is just a normal conducting vortex which is stabilized by solenoidal magnetic supercurrents, j_s , in the surrounding vacuum.

In order to calculate distinctly the energy states (masses) in natural units, firstly we re-derive the field equations of magnetic monopoles current, of the electric flux and energy states.

Therefore, here is adopted a basic dual ($B \Leftrightarrow E$) form of Ginzburg-Landau (G-L) theory [4, 5, 6, 7, 8], which generalizes the London theory to allow the magnitude of the condensate density to vary in space. As before, the superconducting order parameter is a complex function $\psi(\vec{x})$, where $|\psi(\vec{x})|^2$ is the condensate density n_s . Also the wave function is defined as $\psi(\vec{x})=\sqrt{n_s}\exp(i\phi(\vec{x}))$, where n_s is the London (bulk) condensate density, and ϕ are real functions describing the spatial variation of the condensate.

The characteristic scale over which the condensate density varies is ξ, the G-L coherence length or the vortex core dimension. The x denote the radial distance of points from the z-axis, the superconductor occupying the half space $x \triangleright 0$. Outside of the superconductor in the half space $x \triangleleft 0$, one has $B=E=H=H_0$, where, "the external" vector H_0 is parallel to the surface. The ψ theory of superconductivity [3], [4] is an application of the Landau theory of phase transitions to superconductivity. In this case, some scalar complex ψ function fulfils the role of the order parameter.

The final expression for the free energy then takes the form.

$$f=f_n+\int\left\{\begin{matrix}\frac{\hbar^2}{2m}\left|\left(\nabla-i\frac{2e}{\hbar c}A\right)\psi\right|^2+\\ a|\psi|^2+\frac{b}{2}|\psi|^4+\frac{B^2}{8\pi}\end{matrix}\right\}dV \tag{1}$$

One can obtain the basic equations of Ginzburg-Landau theory by varying this functional with respect to A and ψ^*. Carrying first variation with respect to A, we find a simple calculation:

$$\delta f=\int\left[\begin{matrix}c\frac{ie\hbar}{2m}(\psi^*\nabla\phi-\psi\nabla\psi^*)+\\ \frac{2e^2}{m}|\psi|^2A+\frac{curlB}{4\pi}\end{matrix}\right]\delta AdV+\int div\left(\delta A\times B\right)\frac{dV}{4\pi}=0 \tag{2}$$

To minimize the free energy, the expression in the brackets must be equal to zero. This results in the Maxwell equation.

$$curlB=\frac{4\pi}{c}j_s=\frac{1}{c^2\varepsilon_0}j_s(in\_SI) \tag{3}$$

or

$$\nabla\times\nabla\times A=\frac{4\pi}{c}.j_s=\frac{1}{c^2\varepsilon_0}j_s \tag{4}$$

provided that the current density is given by

$$j_s=\frac{ie\hbar}{2m}\left(\psi^*\nabla\psi-\psi\nabla\psi^*\right)+\frac{2e^{*2}}{m.c}|\psi|^2.A \tag{5}$$

The following Equations (6) and (7) form the complete system of the Ginzburg-Landau (G-L) theory.

$$\nabla\times\nabla\times A=\frac{4\pi}{c}.j_s=\frac{1}{c^2\varepsilon_0}j_s \tag{6}$$

According to the definition of n_s we use $\psi=\sqrt{n_s}\exp(i\phi)$.

The second integral is over the surface of the sample. The volume integral vanishes when

$$-\frac{\hbar^2}{4m}\left(\nabla-i\frac{2e}{\hbar c}A\right)^2\psi+a\psi+b|\psi|^2\psi=0 \tag{7}$$

Where $\lambda = \left(\frac{\varepsilon_0 .m.c^2}{n_s .e^2}\right)^{1/2} = 1.17e-16[m]$, and the quantized flux: $\Phi_0 = \frac{\pi\hbar c}{e}$, and $|\Psi|^2 = n_s$; $n_s = 3\_monopoles/V * 1.e-45m^3$, $V = 4/3\pi r^3 = 2$ $r = 0.48[fm]$ $\varepsilon_0 = 8.8e-12[C^2.N^{-1}.m^2]$.

Since the magnetic charge [17] of monopole being

$$g_d = 4\pi\varepsilon_0\frac{\hbar c}{2e} = \frac{4\pi\varepsilon_0\hbar c}{e^2}e = \frac{137}{2}e = 68.5e$$

and assuming that the classical electron radius be equal to "the classical monopole radius" from which one has the monopole mass $m_M = g_d^2 m_e / e^2 = 4700m_e$, and the value of λ remains unmodified.

The superconductors of second kind are those with $\kappa \rhd 1/\sqrt{2}$, and $\lambda \rhd \xi$.

We now consider the phase transition in superconductors of the second kind.

For this we can omit the non-linear $(|\psi|^2\psi)$ term in (7), we have

$$\frac{1}{4m}\left(-i\hbar - \frac{2e}{c}A\right)^2\psi = |a|\psi \tag{8}$$

This equation coincides with the Schrodinger equation for a particle of mass $2m$ and charge $2e$ (in the case of dual, the factor 2 for the charge, which is specific to the "pairs", it is actually 1) in a magnetic field H_0 (in our case the chromo-electrical flux $E(0)$). The quantity $|a|$ plays the role of energy ($E\psi$) of that equation. The minimum energy for such a particle in a uniform electro-magnetic field is $\varepsilon_{(0)} = \frac{1}{2}\hbar\omega_B = \frac{1}{2}\hbar\frac{2eH_0}{8mc} \Rightarrow [J]$, H_0 is an "external" electro-magnetic field of a dipole created by the pair $u\bar{u}$ (the chromo electrical colours field).

$$H_0 = E_0 = \frac{de}{4\pi\varepsilon_0 r^3} \cong 8.33e24\left[\frac{N}{C}\right] \tag{9}$$

where $r \cong 0.05[fm]$ is the electrical flux tube radius, $d = 0.48[fm]$ the distance between the two quarks charges, usually $H[A/m]$, but here is used as $B = \mu_0 H\left[\frac{J}{Am^2}\right]$.

Hence, Equation (8) has a solution only if $|a| \rhd 2\hbar * eH_0/8mc$

or

$$H_0 \le \frac{4mc|a|}{\hbar e} \le H_{c2} = \frac{\Phi_0}{2\pi\xi^2} = \frac{\pi\hbar c}{2\pi e\xi^2} = 8.33e24\left[\frac{N}{C}\right] \tag{10}$$

and in terms of $B_{c2} = H_{c2} = \frac{\pi\hbar c}{2\pi\xi^2.c} = 2.7e16\left[\frac{J}{Am^2}\right]$. The particle energy is $\lambda \rhd \xi$ with $\xi = \frac{\lambda}{\kappa} = \frac{0.117}{1.05} = 0.1114[fm]$, or $\kappa \rhd 1/\sqrt{2} \rhd 1 = 1.05$ (of type II-superconductor).

One of the characteristic lengths for the description of superconductors is called the coherence length. For example, a transition from the superconducting state to a normal state will have a transition layer of finite thickness which is related to the coherence length.

More exactly, this quantity is called the correlation or healing length [4], and is defined as

$$\xi(T) \cong \xi_0\left(\frac{T_c}{T_c - T}\right)^{1/2} \rhd\rhd \xi_0 \tag{11}$$

where $\xi_0 = a\hbar\upsilon_F / E_g$ is for $T \to 0$, $a = 2/\pi$ from [19], E_g -gap energy, k_B Boltzmann constant; at confinement $T_c = 175[MeV] \to 2e12[K]$, and the Fermi velocity of electrons (monopoles) is

$$\upsilon_F = \frac{\sqrt{2*4700m_e E_F}}{4700m_e} \tag{12}$$

where as the Fermi energy we have for monopoles condensate viewed as bosons condensate

$$E_g = E_{bosonCond} = 3.31\frac{\hbar^2 n_s^{2/3}}{4700m_e} \cong T_c k_B = 0.7E_F$$

$$E_F = \frac{\hbar^2}{2*4700m_e}\left(3\pi^2 n_s\right)^{2/3} \tag{13}$$

where numerically, we have:

$$E_F = \frac{1.06e-34^2}{2*4700*9.e-31}\left(3\pi^2 * 3/(V*1.e-45)\right)^{2/3} = 9.32e-12[J] \to 55[MeV]$$

where $V = 1.5[fm]^3$, and the velocity of monopole is

$$\upsilon_F = 0.55e8 < c = 2.997e8[m/s]$$

and

$$\xi_0 = 0.6*0.7\frac{1.06e-34*0.55e8}{1.38e-23*2.e12} = 1.02e-16[m] \text{ at } T \to 0 \tag{14}$$

Usually, the flux quantum is defined as:

$$\Phi_0 = \pi\hbar c/e \to usually\frac{\pi\hbar}{e} = 2.07e-15[Tm^2] \tag{15}$$

In [4], the G-L equations are solved analytically only for $\lambda \rhd\rhd \xi$ (near T_c this means $\kappa \rhd\rhd 1$).

Thus, in the range $\lambda \rhd\rhd x \rhd\rhd \xi$ (16)

The induction B is given by: $B(x)=\frac{2\Phi_0}{2\pi\lambda^2 c}\log\left(\frac{\lambda}{x}\right)$ (17)

This equation is valid only at all distances $x \rhd\rhd \xi$ (18)

The solution at $x\to\infty$ is $B(r)=const\cdot \mathrm{K}_0(x/\lambda)$, where K_0 is the Hankel function of imaginary argument. The coefficient must be defined by matching with the solution of (17). Using the asymptotic formula $\mathrm{K}_0(x)\approx\log(2/\gamma x)$ for $x\lhd\lhd 1$, where $\gamma=e^C\cong 1.78$ (C is Euler's constant), we finally have

$$B(x)=\frac{2\Phi_0}{2\pi\lambda^2 c}\mathrm{K}_0(x/\lambda) \qquad (19)$$

Using equation (19), we can rewrite (17) as:

$$B(x)=\frac{2\Phi_0}{2\pi\lambda^2 c}\log\frac{2\lambda}{\gamma x},\quad x\lhd\lhd\lambda \qquad (19.1)$$

In opposite limit of large distances one can use the asymptotic expression $\mathrm{K}_0(x)\approx(\pi/2x)^{1/2}e^{-x}$ for $x\rhd\rhd 1$. Thus, at large distances from the axis of the vortex line the field decreases according to

$$B(x)=\frac{2\Phi_0}{c(8\pi x\lambda^3)^{1/2}}e^{-x/\lambda},\quad x\rhd\rhd\lambda \qquad (20)$$

Accordingly the superconductive current density decreases (in SI):

$$j_\phi=-\frac{c}{4\pi}\frac{dB}{dx}(4\pi c\varepsilon_0)=\frac{2c^2\varepsilon_0\Phi_0}{8(2\pi^3 x\lambda^5)^{1/2}c}e^{-x/\lambda} \qquad (21)$$

We can now calculate the energy ε of the vortex line; we obtain for the energy per unit length of vortex line.

$$\varepsilon=c^2\varepsilon_0\left(\frac{2\Phi_0}{4\pi\lambda c}\right)^2\log\left(\frac{\lambda}{\xi}\right) \qquad (22)$$

Here, the factor $4\pi c\varepsilon_0$ is used to convert from $(cgs)\to(SI)$.

Because the magnetic induction of the monopoles current which is powered by electric field given by a pair of quarks (H_0), it has the raw flow consequences squeezing this cromoelectrical flux into a vortex line, followed by forcing an organization into a triangular Abrikosov lattice, see Figs. 1a, b.

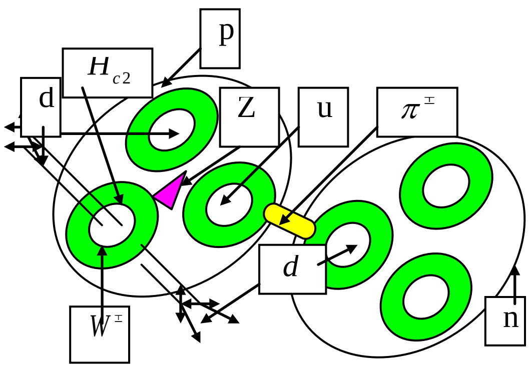

Fig. 1a Abrikosov's triangular lattice for a nucleon (proposal)

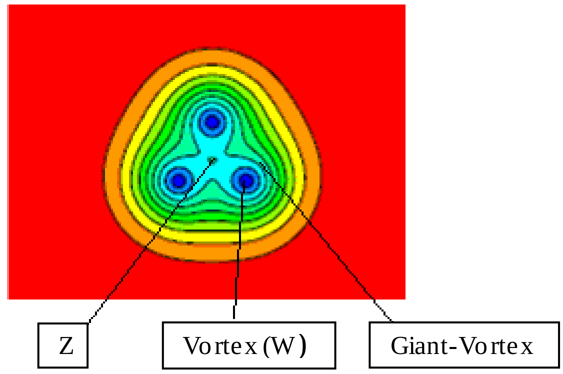

Fig.1b The Giant-Vortex (after ref. [24]) type arrangement for the nucleon (only as an illustration)

The core of every vortex can be considered to contain a vortex line, and every particle in the vortex can be considered to be circulating around the vortex line.

The presence of vortex line increases Z, Vortex(W), the free energy of the superconducting media with εL, thus it is thermodynamically favorable if the contribution is negative; i.e. if $\varepsilon L-\Phi_0/c\cdot H_0\,L/4\pi\mu\lhd 0$, and $B_0=\frac{H_0}{\mu_0}$,

$$\mu_0=1/c^2\varepsilon_0\text{, or }H_0\lhd H_{c1}=\frac{4\pi\mu_0 c}{\Phi_0} \qquad (23)$$

Substituting (22) in (23), we find the lower critical field

$$B_0=H_{c1}=\frac{2\Phi_0}{2\pi\lambda^2}\log\left(\frac{\lambda}{\xi}\right)=\frac{\pi\hbar c}{\pi\lambda^2 c}\log(\kappa)=1.e15\left[\frac{J}{Am^2}\right] \qquad (24)$$

$\xi=0.1114$, and when near the axis, for $x\equiv 0.116\cong\xi$ from (20) when the induction is $B(\xi)\cong 2.e15\cong 2H_{c1}$ (25)

The energy of interaction of two vortex lines is separated by a distance d from each other is given as:

$$\varepsilon_{\mathrm{int}}(d)=\frac{2\Phi_0}{4\pi}B_d(x)=\frac{4\Phi_0^2}{8\pi^2\lambda^2}\mathrm{K}_0\left(\frac{d}{\lambda}\right) \qquad (26)$$

One can use the asymptotic expression for $\varepsilon_{\mathrm{int}}$ (see Eq. (27)).

$$\varepsilon_{\mathrm{int}}=\frac{4\Phi_0^2}{2^{7/2}\pi^{3/2}\lambda^2}\left(\frac{\lambda}{d}\right)^{1/2}e^{-x/\lambda},\ x\rhd\rhd\lambda \qquad (27)$$

When the distance $d\approx\lambda\rhd\rhd\xi$, the cores of vortex lines overlap [4].

Let us consider a closed contour near the surface of the cylinder. The change of wave function on passing round the contour is $2\pi\nu S$, where S is the cross-section area of the cylinder and ν is the number of vortex lines. The electric flux is

$$\Phi=2\Phi_0\nu S-\frac{2m}{e\hbar}\oint\frac{j_s}{n_s}\cdot dl \qquad (28)$$

Let us recall that similarly relationship [4, 5]. It was introduced for the first time by London, called fluxoid equation.

Each fluixoid, or vortex, is associated with a single quantum of flux represented as Φ_0, and is surrounded by a circulating suppercurrent, j_s, of spatial extent, λ. As the applied field increases, the fluxoids begin to interact and as the consequence ensembles themselves into a lattice. A simple geometrical argument for the spacing, d of a triangular lattice then gives the flux quantization condition [13],

$$Bd^2 = \frac{2}{\sqrt{3}}\Phi_0 \tag{29}$$

where B is the induction.

The solution of Ginzburg-Landau phenomenological free energy [13] is useful for understanding the Abrikosov flux lattice. The coordinate-dependent order parameter ϕ describes the flux vortices of periodicity of a triangular lattice. Fluctuations from ϕ change the state to ψ; the minimization of free energy with respect to ψ, gives the ground state $\phi(r/0)$.

The free energy is given by,

$$f = f_n + \int \left\{ \begin{array}{l} \frac{\hbar^2}{2m}\left|\left(\nabla - i\frac{2e}{\hbar c}A\right)\psi\right|^2 \\ +a|\psi|^2 + \frac{b}{2}|\psi|^4 \\ +\frac{\left(B-H_0\right)^2}{8\pi} \end{array} \right\} dV \tag{30}$$

The average magnetic induction is $\vec{B}(-y,0,0)$. The free energy has solutions of vortices of triangular form. The coordinates of the three vertices of a triangular vortex are given by $(0,0),(l,0)$, and $\left(\frac{1}{2},\frac{\sqrt{3}}{2}\right)l$. The fluctuation from ground state corresponding to that of triangular lattice is that for small fluctuations. The deviation of the free energy from the mean-field value $F-F_{FM}$ with respect to the thermal energy, k_BT, can be used to obtain the physical properties of the fluctuations which are useful for understanding the melted vortex lattices. The deviation from the triangular Abrikosov lattice is defined as

$$D = \langle\left|\psi - a_1\phi\left(r/0\right)\right|^2\rangle / a_1^2 \tag{31}$$

which uses the spatial and thermal averages calculated with the probability $\exp\left(-F/k_BT\right)$. Classically,

$$D = \frac{k_BT}{F-F_{MF}} \tag{32}$$

measures the fluctuations from the triangular vortex state. The fluctuation in the distance between vortexes becomes:

-Case 1, $\left(1-T_{FM}/T_c\right) \cong 10^{-5}c^{-4/3}B^{2/3}$ (33)

-Case 2, $1-T_{FM}/T_c \cong c^{-1}B^{5/4}$ (34)

-Case 3, a vortex transition below the transition temperature see [13],

where, T_{FM}, the flux-lattice melting temperature, and $c=0.1$ from Lindemann criterion of lattice melting when $d^2 = c^2l^2$, the flux quantization condition $l^2 = \Phi_0/B$, $B = 2\pi n/\kappa$, where $\kappa = \frac{e\sqrt{2}}{\hbar c}\lambda^2 H_c(T)$, and $H_c = \kappa/\ln\kappa.H_{c1}$.

For numerical values $T_c = 175[MeV]$, in case of symmetry breaking, in case 1, it results $T_{FM} \cong T_c$, and in Case 2, it results $T_{FM} \cong 100[keV]$ by using (29) in place of $\Phi_0/B \cong d^2$ with $d = 0.3982[fm]$ (a very precisely value), and $\kappa \cong 1$, which is the temperature of fusion (melting!) of two protons.

This triangular lattice corresponds to the arrangement of the quarks pairs $u\bar{u}, u\bar{u}, d\bar{d}$ in the frame of a nucleon, see Fig.1a, b.

A direct numerical analysis allows obtaining the following values for the current, force and energy. Thus, from (21) the current is given by:

$$j_\varphi \cong 1.15e7[A/fm^2] \tag{35}$$

where $x \cong \lambda$.

For $x = 2\cdot\lambda$, the current density decreases at $j_F \cong 3.e5[A/fm^2]$.

Note that velocity υ_F, moreover, if one considers the monopole current given by equation as $j_\phi = n_s v_F g_D$, where the magnetic charge is:

$$g_d = 4\pi\varepsilon_0\frac{\hbar c}{2e} = \frac{4\pi\varepsilon_0\hbar c}{e^2}e = \frac{137}{2}e = 68.5e \tag{36}$$

If we use the range $x \cong 0.1 \le \lambda$, then the current is obtained by derivation of (19.1):

$$j_\phi = \frac{1}{4}\frac{1}{x}\frac{1}{\lambda^2}\frac{4\pi\hbar c}{e}\frac{c^2\varepsilon_0}{c} = \frac{1}{4}\frac{1}{x}\frac{1}{\lambda^2}g_D c = \frac{n_s}{V}\upsilon_{Fi}g_D \rightarrow \tag{37}$$

$$\frac{\upsilon_{Fi}}{c} = \frac{1}{9.89} = 0.302e8[m/s]$$

The Lorentz' force to squeeze the flux tube is:

$$F_L = qv_{Fi}B \cong 1.6e-19*0.1*2.992e8*4.7e15 = 2.25.e4[N] \tag{38}$$

when B is given by (19.1) and $x \cong \lambda$, for the upper limit:

$$B(x) \cong 2.35e15[J/Am^2] \tag{39}$$

With B from (20) and for $x \rhd\rhd \lambda$, we have

$$B(x) = 3.8e-16\left[\frac{J}{Am^2}\right] \quad (40)$$

where $x = 72\lambda = 8.4[fm]$, then, the force becomes $F_L \cong 1.8e-26[N]$, or in terms of energy

$$\varepsilon_{barrier} = F_L * x = 945[MeV] \quad (41)$$

or the nucleon overall. In case of $x \cong \xi \rightarrow (0)$, in (17),

$$B(0) = 1.03e15\left[\frac{J}{Am^2}\right] \quad (42)$$

which respect (25).

The magnetic energy results from (22), and for ($\lambda \rhd\rhd x \rhd\rhd \xi$) from (16):

$$\varepsilon = 1.09e-10\left[J/fm\right] \Rightarrow 0.66[GeV/fm] \quad (43)$$

The force on the flux tube which corresponds with the well known "string tension" defined in refs. [9-11].

Now, from (27) and $d \approx (4 \div 6)\lambda \rhd\rhd \xi$, we have

$$\varepsilon_{\text{int}} = 2.3e-11\left[J/fm\right] \Rightarrow 144[MeV] \quad (44)$$

What would be the value of the mass of the pion π^+, composed of a pair of quarks $u\overline{d}$ interacting at a distance $d \approx 2/3 \cong 5.65 * \lambda \cong 0.66[fm]$ of the radius of the nucleus.

Now, others important values of energy, as will be necessarily in following, it could be calculated:

$$\varepsilon_0(0) = \varepsilon_{\text{int}}(d = x - \lambda; \; x = 0.14) * 0.117[fm] \cong 1.e-09[J] \quad (45)$$

and from (38) with $x \cong \xi = 0.107[fm]$ (46)

$$\varepsilon_{0h} = Vc^2\varepsilon_0(2H_{c1})^2/8\pi = 5.e-11[J] \quad (47)$$

Now, the vortex energy is:

$$\varepsilon_{vortex} = Vc^2\varepsilon_0 H_{c2}^2/8\pi = 1.16e-08[J] \quad (47.1)$$

where V is the volume, see Fig. 1a, b. Accordingly, the corresponding equivalently masses are $M = \varepsilon_{vortex}/c^2 \Rightarrow 73[GeV]$, which seems to be equal to the mass of W boson.

The energy of the neutral boson Z is assimilated with the vortex-vortex three pairs interaction energy [24], $\varepsilon_Z = 3 * \varepsilon_{\text{int}-pair} = 91[GeV]$, when from (27)

$$\varepsilon_{\text{int}-pair} = \varepsilon_{\text{int}}(d = 0.117 - 0.116; \; x = 1.4\lambda) = 4.85e-09[J] \rightarrow 30.33[GeV] \quad (48)$$

is the energy of each of three pairs of vortex outermost $(d \cong 0)$ vortices lines which interacting (repel) at the center of the triangle situated at $x = 1.4\lambda$, thus, being generated a neutral current in the zone of Z during the triangular arrangement of the lattice, see Fig. 1a, b.

Now, it is possible that the vortices start to coalesce into a giant vortex (GV) [26], see, Fig. 1b.,

Thus, from (27), results another energy state-maximum possible ($d \cong 0$), probable that of Higgs boson (H):

$$\varepsilon_H = 3 * \varepsilon_{\text{int}}(d = 0.117 - 0.116; x = \lambda) = 2.17e-08[J] \rightarrow 135[GeV]$$

Notice that this is not in fact a particle, since it contain others subparticles ($W, Z, u, d, monopoles$), so during high energy protons collision (CERN), it cannot be obtained as itself.

Here, a factor of 2 was introduced to correct on $2e$ for "pairs" in the G-L model.

III. THE PHOTONUCLEAR REACTION MECHANISM IN G-L THEORY

As in [2a], we derive the energy barrier for vortex crossing and crossing rate from the standard Ginzburg-Landau (GL) functional with respect to the superconducting order parameter $\psi(r)$ (normalized to its zero-field value in the absence of current) and the vector potential A in the presence of monopoles current induced magnetic field H. The Gibbs energy is given by (30).

Like in [2], we assume that in sufficiently narrow strips, $w \cong r_{nucleon}$, (a) the cloud covers the entire width of strip when it reaches its maximum size; (b) the quasiparticle density in the cloud (hot belt) is close to uniform; and (c) quasiparticles suppress the superconducting order parameter inside the hot belt, but their density is not sufficient to convert the hot belt to the normal state. Thus the superconducting condensation energy density $H_{ch}^2/8\pi$ in the hot belt satisfies the inequalities $0 \lhd H_{ch}^2/8\pi \lhd H_{c(0)}^2/8\pi$.

It follows that the vortex crossing rate via hot belt (denoted by subscript h), $R_{vh}(I)$, is enhanced in comparison with that for dark counts, because the parameter $v_h = \varepsilon_{0h}/k_B T \approx H_{ch}^2/8\pi k_B T$ is reduced in comparison with $v_0 = \varepsilon_0/T$, and $\varepsilon_0 = \frac{\Phi_0 I_0}{\pi c} = \varepsilon_{\text{int}} \cong 1.e-09[J]$, from (45).

There are three superconducting current-biased regions to be considered, which are separated by three characteristic currents $I_h^* \lhd I_{ch} \lhd I_{c0}$. Currents below I_h^* counts are absent, because vortex crossings do not result in the formation of normal-state belt. The "hot" current I_h is determined through the energy balance for destroying the superconducting condensate in the hot belt similar to that for dark counts, however, with the thermodynamic field $H_{ch} \lhd H_c(0) = H_{c1}$, from (24).

For lower currents in the interval $I_{ch} \rhd I \rhd I_h^*$, the rate of photon counts shows a power-law current dependence, $R_{pc}(I) \approx I^{v_h+1}$

Here, we model the temperature dependent parameters, $I_{ch}(T) = I_{ch}(0)\varepsilon_T^3$, $v_i(T) = v_i(0)\varepsilon_T^2/T$, with $\varepsilon_T = \left(1 - T/T_c\right)^{1/2}$.

For currents $I \geq I_c/3$, the energy released by phase slip is sufficient to destroy superconductivity.

In the region $I_h^* < I < I^* \cong I_{c0}/3$, vortex crossings via the hot belt destroy the superconducting state inside the belt during the time τ of the hot spot's lifetime. During this time, the belt is in the normal state, which causes the "vortex-assisted" photon count.

A sketch of the strip and of the belt across is shown in Fig. 2.

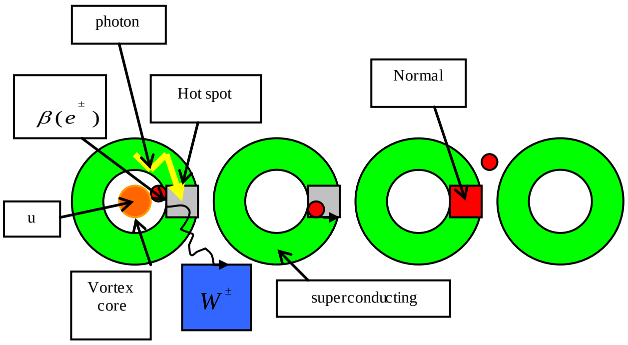

Fig. 2 The proposed photonuclear mechanism: from left to right, illustration of incident photon creating superconducting hot spot (hot belt) across nucleon, followed by athermally induced vortex crossing together with an electron (bias current), which turns superconducting hot belt into the normal state resulting in a vortex assisted photon beta decay

If $I_{c0} \triangleright I \triangleright I_{ch}$, the rate of single photon counts, R_{pc}, is the same as the rate for hot spot formation R_h, because the barrier for vortex crossing is now absent. For hot counts R_h, we have $R_h = \eta_h R_p$, where R_p is the photon rate and η_h is the quantum efficiency of hot spot formation caused by a single photon.

The vortex assisted photon count rate from [2a] is:

$$R_{pc} = R_h\left[1 - \exp(-\Re)\right] \tag{49}$$

where:

$$R_v(I, \nu_h) = \frac{4k_B Tc^2 R}{\pi\Phi_0^2}\frac{\xi}{w}\left(\frac{\nu_h}{2\pi}\right)^{1/2}\left(\frac{I}{I_{ch}}\right)^{\nu_h+1} \tag{50}$$

$$\Re \approx \frac{\tau_{GL} R_v}{\nu_0 - \nu_h}\frac{1-(I_{ch}/I)^{\nu_h-\nu_1-1}}{\ln(I_{ch}/I)} \tag{51}$$

$$I_{ch} = I_{c0}\left(\nu_h/\nu_0\right)^{3/2} \tag{52}$$

In the case of β^- disintegration $n \rightarrow p + e^- + \nu_e$,

or $udd \rightarrow uud + e^- + \nu_e + W^-(80GeV)$,

or $d(-1/3e) + 2*3/3e = u(+2/3e) + e$,

or $e + u(2/3e) - 2*3/3e = d(-1/3e)$ (53)

When the vortex equilibrium is disturbed by the transformation of one quark ($d \rightarrow u$), it will be accompanied by a release of a W boson or the crossing vortex in this model.

We can suppose than along the hot belt induced by the incident photon, the charge $2e + W$ creates a bias current ($I > 2/3e[(1/(\nu_h/\nu_0)^{3/2}) \cong 3] \Rightarrow 2e$) who circulates due of the potential difference between the vortex and the rest of isotope.

At the first sight, the ohmic resistance of this ad-hoc electrical circuit created by the bias current is given as:

$$R = \frac{U_\beta}{\tau_{GL}}\frac{1}{V_{vortex}^2} \tag{54}$$

where the vortex potential is $V_{vortex} = H_0\xi$, H_0 from (30.1), and the power is $U_\beta/\tau \cong \varepsilon_{vortex(W^\pm)}/\tau$, where U_β is given by (47.1), and $\tau_{GL} = \pi\hbar/(8k_B T_c) = 1.5e-24[s]$, the Ginzburg-Landau life time of $W^\pm$ bosons.

Numerically, with $T_c = 175MeV$, $E_{prag} = k_B T$, result in $\nu_0 = \varepsilon_w/k_B T_c = 1.e-09/(1.38e-23*2.e12) = 36.2$, where ε_W from (43); $\nu_h = \varepsilon_{\text{int}>2\lambda}/E_{ph} = 5.e-11/E_{prag}$, where ε_{int} from (46).

The value of E_{prag} is determined by trials in order to have $R_{pc}/R_h \cong 1$.

Since, a photonuclear reaction could be viewed as a vortex assisted photon beta decay, and with the above data related on energies of vortex and on currents from inside of the nucleon, are calculated the beta decay rates.

Now, let us discuss the ${}^{99}Mo \rightarrow {}^{99m}Tc$ isotopes, which are widely used as SPECT isotopes [1]. The ${}^{99}Mo$ ($\beta^-, T_{1/2} = 65h, Q = 1.356MeV$) isotopes are produced by ${}^{100}Mo(\gamma, n)$ reactions and also ${}^{100}Mo(\gamma, p)$ reactions followed by β^- decays.

From our model results, only from β^- decay chain (${}^{99}_{42}Mo \rightarrow {}^{99m}_{43}Tc$), a decay rate of $R_{pc} = 4.7\times10^7\ counts/s$ is attained, with the incident photon rate of $R_h = 1.e13\ photons/s$ and of $\sim 15MeV$ photons energy (or $R_{pc}/R_h \cong 4.7\times10^{-6}$). Therefore, in order to transmute entirely ($R_{pc}/R_h \cong 1$) it needs, or an irradiation of $60h \cong T_{1/2} = 65h$, either, to proceed much faster (instantly), the photons energy must be of a very precisely threshold value $\geq E_{prag} = 20Mev$, see Fig. 3.

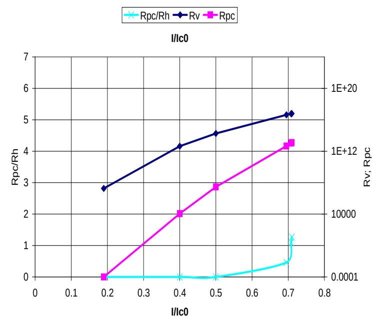

Fig. 3 The vortex-assisted photon count rate R_{pc}/R_h vs. *bias current* given in Eqs. (49 – 53)

These are the main results of this model, namely, a threshold value of photon energy, for an incident rate $R_{pc} = R_h = 1\times10^{13}[photons/s]$, or in other words, the necessary parameters of photons source.

Notice that, at these parameters, the same type of instant rates it happens for all beta-decay isotopes, like: ^{85}Kr , $Q_\beta = 0.687MeV$ and $T_{1/2} = 48h$, $\gamma - ray = 514KeV(0.46\%) \to T_{1/2} = 10.756yr$; $\gamma - ray = 151KeV(95\%) \to T_{1/2} = 4.48h$ $^{137}_{55}Cs \to ^{137}_{56}Ba + e^- + \overline{\nu}$, $Q_\beta = 1.175MeV$, $\gamma - ray = 661KeV(85\%) \to T_{1/2} = 30.8yr$ etc., i.e. these rates are not dependent of the nuclide type, but only on E_{prag} .

As it was mentioned in [1], CPIT with large efficiency is quite attractive from ecological view points. Since the GeV electrons stored in a storage ring lose little their energy via interactions with laser photons, they remain in the ring. The laser electron photons are efficiently used for production of desired radioisotopes (RIs) by (γ, n) reaction when a valence neutron of the nuclide is dislocated. Then the overall efficiency of the RI production is larger than that of the charged particle accelerators and nuclear reactors. Fast neutrons are used for nuclear transmutation but only a small fraction of the charged particles are used to produce the fast neutrons. Intense electron accelerators provide bremsstrahlung photons for photonuclear isotope transmutation but most of photons are below the threshold energy of the photonuclear reaction. There are several programs of intense photon sources under progress MAGa-ray, such as the project at LLNL for high intensity photons with 10^{12} photons/sec in the MeV region and so on. ELI-NP is the one at Romania [35] for higher energy photons with 10^{13} photons/sec in the GR energy region of $E(\gamma) \geq 19.5[MeV]$. They plan to achieve the intensity of around $10^{15}/s$. In Tokai Japan, the ERL (Energy Recovery Liniac) project is under progress to provide intense photons for resonance fluorescence.

A. Beta Decay Halftime Calculation with a G-L Model

Below we will demonstrate that the mechanism for beta decay of radioisotopes is the same as the dark counts in the case of superconductors [2b].

In [2b] we derive the energy barriers for three dissipative processes mentioned within the GL theory. In the following, by analogy wit ref. [2b], we consider a thin-film strip (one of three vortexes of the nucleus) of width $w = r * \lambda$ (see Fig. 1a, b). We choose the coordinates so that it is $0 \leq x \leq w$. Since we are interested in bias currents which may approach depairing values, the suppression of the superconducting order parameter (ψ) must be taken into account. Also as in [2b], it used the standard GL functional, given above in (1).

A vortex crossing from one strip edge to the opposite one induces a phase slip $2\pi - \varphi$ (a every phase slip meaning Φ_0 energy released) without creating a normal region across the strip (one of three vortexes of nucleus) width.

From [2], the asymptotic estimate for the dark counts rate, results as:

$$R_\nu(I, \nu_h) = \frac{4k_B T c^2 R_\Omega}{\pi \Phi_0^2} \left(\frac{\pi \nu_h^3}{2}\right)^{1/2} \left(\frac{\pi\xi}{w}\right)^{\nu_h+1} Y\left(\frac{I}{\mu^2 I_0}\right) \quad (55)$$

and where the bias current is :

$$I = \frac{2w}{\pi\xi} I_0 \kappa(1-\kappa^2) \quad (56)$$

$$I_0 = \varepsilon_0 \frac{c\Phi_0}{8\pi\Lambda}; \Lambda = \frac{2\lambda^2}{h_z} \quad (57)$$

Here, $h_z \cong \lambda$ -the axial (z) height of the monopole condensate.

Here, the critical current at which the energy barrier vanishes for a single vortex crossing:

$$I_c = \frac{2\mu^2 w I_0}{2.72\pi\xi}; \quad (58)$$

And the thermodynamic critical field is:

$$H_c = \frac{\Phi_0}{2\sqrt{2}\pi\xi\lambda c} \quad (59)$$

where $\mu^2 = 1 - \kappa^2$, and

$$Y(z) = \left(1+z^2\right)^{(\nu+1)/2} \exp\left[\nu z \tan^{-1}\left(1/z\right)\right] \quad (60)$$

where $\upsilon_h = \tau_{GL}(\varepsilon_{vortex} - Q_{bind})/\hbar$ is the energy of the vortex during crossing the barrier of height $\varepsilon_{vortex} - Q_{bind}$ by quantum tunneling in place of the thermal activation used in [2b], and overpassing an ohmic resistance along a transverse path way of the nuclide:

$$R_\Omega = \frac{R_q R_{nuclide}}{R_q + 2\pi(\xi/w)^2 R_{nuclide}} \quad (61)$$

Here, $\varepsilon_{vortex} = M_W$ from (47.1), and Q_{bind} is the beta decay energy as obtained from the data of each radionuclide of beta decay type (see Chart of Nuclides 2010).

In the case of beta disintegration $n \to p + e^- + \nu_e$, or $udd \to uud + e^- + \nu_e + W^-(80GeV)$ and the bias current is: $d(-1/3e) + 2*3/3e = u(+2/3e) + e$.

In β^+ decay, energy is used to convert a proton into a neutron, while emitting a positron (e^+) and an electron neutrino (ν_e): $Energy + p \to n + e^+ + \nu_e$.

In all the cases where β^+ decay is allowed energetically (and the proton is a part of a nucleus with electron shells), it is accompanied by the electron capture (EC) process, when an atomic electron is captured by a nucleus with the emission of a neutrino: $Energy + p + e^- \to n + \nu_e$.

Therefore, the ad-hoc bias current created during vortex crossing through the energy barrier is: $e + u(2/3e) - 2*3/3e = d(-1/3e)$

At the first sight, the ohmic resistance of this ad-hoc electrical circuit created by the bias current $I(e\mp)$ due of quarks transformation $(d \to u)$, or $(EC(u \to d)$, is given as: $R_{nuclide} = \frac{Q_{bind}}{\tau_{GL}} \frac{1}{V_{vortex}^2}$ (62)

and the superconducting quantum resistance is $R_q = \hbar/(2e)^2 = 6.5k\Omega$, where the vortex potential is $V_{vortex} = H_0 \xi$, H_0 from (9).

Giordano [21] has suggested that phase slips due to that macroscopic quantum tunneling may be the cause of the low temperature resistance tail in the 1D wire he studied in zero fields. One possible mechanism for our low temperature resistivity tail could be quantum tunneling of vortices through the energy barrier [22]. One expects a crossover from thermal activation to quantum tunneling to occur when [23], in (55) in place of thermal activation we use the quantum tunneling: $k_B T = \hbar/\tau_{GL}$. A vortex moves from $x = 0 \to w$, during the time τ_{GL}.

We estimate the total interaction energy interaction with the neighbourhood vortexes or with the one giant-vortex, Fig.1b, of others nucleons from the nuclide nucleus, during the time τ_{GL} along the vortex path by matching (56), (57) and (59) as:

$$Q_{bind} \cong (\Phi_0 I/c) = \frac{\Phi_0}{c}\frac{2w}{\pi\xi}\kappa(1-\kappa^2)\frac{\varepsilon_0 c \Phi_0 h_z}{8\pi 2\lambda^2} = = \frac{c^2 \varepsilon_0 \pi \xi^2 h_z}{2} H_c^2 \frac{I}{I_0} \quad (63)$$

where the ratio $\frac{I}{I_0 \mu^2} = z$ was chosen as a variable in (55), through (60). In fact, this is the work done by the Lorentz force on the vortex path of the length w.

Now, we proceed to application to some radionuclides which decay beta, and begin with the neutron.

The lifetime of the free neutron is a basic physical quantity, which is relevant in a variety of different fields of particle and astrophysics. Being directly related to the weak interaction characteristics, it plays a vital role in the determination of the basic parameters like coupling constants or quark mixing angles as well as for all cross sections related to weak $p - n$ interaction. From the most precise measurement within this class of experiments, we got the result of $\tau_n = 886.3[s]$.

From "Chart of Nuclides 2010", we can get the result of ^{99}Mo ($\beta^-, T_{1/2} = 65h, Q = 1.356MeV$); ^{85}Kr , $Q_\beta = 0.687MeV$ and $T_{1/2} = 48h$, $\gamma - ray = 514KeV(0.46\%) \to T_{1/2} = 10.756yr$; $\gamma - ray = 151KeV(95\%) \to T_{1/2} = 4.48h$; $^{137}_{55}Cs \to {}^{137}_{56}Ba + e^- + \bar{\nu}$, $Q_\beta = 1.175MeV$, $\gamma - ray = 661KeV(85\%) \to T_{1/2} = 30.8yr$,etc

Now numerically, with these data, we have the result of $\tau_{GL} = 1.5e-24[s]$, $Y = 2560$, $\nu_h \cong 157$, and with $w = r\lambda$ as variable, the evolutions of dark count rate R_v, and of R_Ω, for different isotopes are given in Fig. 3.

Here, the fraction of the bias current to critical current I/I_0 as used in $Y(z)$ from (60) was deduced separately for $^{137}_{55}Cs$ as that of the plateau zone in Fig. 4, respectively of $I/\mu^2 I_0 \cong 0.005$, by using the condition $R_v/T^{1/2} \cong 1$. We can observe that this value corresponds with the expected value from quarks transformation of $\cong 1(e^\pm) * v_{vortex} * 1.6e-19 r_0[Am] \to 124[A]$, where the vortex crossing velocity is $v_{vortx} = \lambda/\tau_{GL}$, and r_0 -K shell radius. Therefore, the bias current, which is perpendicularly on the monopoles current, is $I = 0.005\mu^2 I_0 = 150[A]$, where, $\mu^2 = 0.111$, and the monopoles current is $I_0 \cong 3.e5[A]$ as given by (57), and $I_c = 1.6e4[A]$ from (58). From (62), the results will be $Q_{bind} \cong 2.92e-13[J]$ or near equally with Q_β of the almost of nuclides, for example, for ^{100}Mo , $Q_\beta = 1.356MeV \to 2.17e-13[J]$.

Now, in case of quantum tunnelling, the transmission coefficient [20] is $T = e^{-\frac{\varepsilon_0 \tau_{GL}}{\hbar}} \cong 1.e-66$, which is too small, meaning that a vortex crossing from one strip edge to the opposite one induces a phase slip, which is the only viable mechanism for dark counts (beta decay).

Thus, it has established a logarithmic equation of the β decay rate which resulting a straight line as a function of the barrier width $(w = r\lambda)$ for every nuclide, as shown in Fig. 5. It decreases in case of long lived nuclides, like ^{60}Fe. Therefore, this evolution is a decisive validation test of entirely model. The factor r describes the interactions of the nucleons inside of the nucleus, being a complex function of Z, N, A, Q_{bind}.

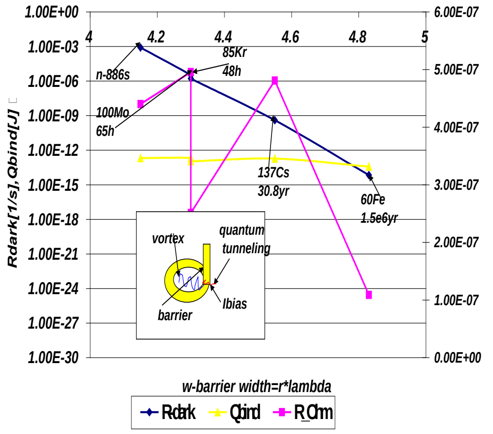

Fig. 4 The evolution of dark count (β decay) rate as function of barrier width

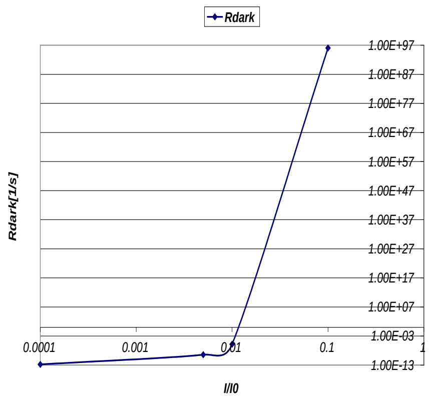

Fig. 5 The evolution of the dark count rate (β) decay as a function of the bias current

B. Who is in Fact the Parameter $w = r\lambda$ *?*

In order to answer to this question, in the following we will look to the vortexes interactions [24] vis-à-vis of the nucleus substructure models $[25-33]$.

Firstly, from [24], for vortex-vortex interaction (V-V) at large separation, using the asymptotic form of the modified Bessel functions, it is:

$$\Omega(d \to \infty) = \gamma d^{-1/2}\left(\delta e^{-d} - \sqrt{\mu}e^{-\mu d}\right) \qquad (64)$$

where $d(\lambda) = r\lambda$ is the separation distance; $\mu = \sqrt{2}\kappa$, and $\gamma = -12.503$; $\delta = 0.3127$ are fitting parameters.

Furthermore, in [24], it shows that the interaction between an antivortex and a giant vortex is always attractive as well.

In the absence of lateral confinement, a giant vortex is a stable (unstable) state in type-I (type-II) systems and can interact as such with other vortices, and this motivates us to investigate the interaction force between a vortex and a giant vortex.

Also in [24], it is suggested that the fitting function given by the following equation can not only be used for the $V-Vs$, but also for the $V-GV$ interaction force.

$$\Omega_{fit}(d) = \eta_1 \frac{d^{\eta_3}}{1+\eta_2 d^{\eta_3+\frac{1}{2}}}\left(\eta_4 e^{-d} - \sqrt{\mu}e^{-\mu d}\right) \qquad (65)$$

where $\eta_i (i = 1,2,3,4)$ are four fitting parameters.

The values of the four fitting parameters are given in Table II of [24], for μ from $0.2-2.5$. In our case, $\mu = \sqrt{2}\kappa \cong 1.4$ results in $\eta_1 = 1.237e-02; \eta_2 = 1.55e-03; \eta_3 = 4.248; \eta_4 = 1.183$

When two vortices or a vortex and a giant vortex are brought close to each other, they merge forming a single giant vortex state with vorticity $n = n_1 + n_2$, and in the limit of small separation, $V-V$ or $V-GV$ forces will be very weak. Conversely, a vortex and an antivortex attract and annihilate both in type I and type II superconductors. As follows, from theory [24], the V-AV interaction is always attractive.

However, at some critical $V-AV$ separation, $d_E = 0.337 + 31.249(1+10.264\mu)^{-0.6855}$, or $d_E = 4.96\lambda$ becomes unstable as the $V-AV$ separation is reduced at $d < d_A$, $d_A = 0.337 + 12.222(1+2.461\mu)^{-0.79}$ or $d_A = 3.95\lambda$. For molecular dynamics studies of the $V-AV$ motion, one should consider the critical separation d_A as the separation where the $V-AV$ pair annihilates.

The fit [24] of the numerically obtained $V-AV$ interaction force for $d > d_E$, yields a single expression:

$$\begin{aligned}\Omega = &-(2.879 + .415\mu^{-3.166})\mathrm{K}_1(d) + \\ &(0.2258 - 1.044e^{1.866\mu})\mu\mathrm{K}_1(\mu d)\end{aligned} \qquad (66)$$

where the approximation of the Bessel function is $K_1(d) = \frac{\pi}{\sqrt{2\pi d}}\exp(-d)$, which is expected to provide an accurate description of the V-AV interaction force, at separations $d > d_E$, for any value of μ.

Now, atomic nuclei is known to exhibit changes of their energy levels and electromagnetic transition rates among them when the number of protons and/ or neutrons is modified, resulting in shape phase transitions from one kind of collective behaviour to another. These transitions are not phase transitions of the usual thermodynamic type; they are quantum phase transitions QPT [25] (initially called ground state phase transitions).

A main conclusion from [25] is that the effect of the fermionic impurity ($e^{\pm}$ as in case of $\beta^{\pm}$ decay) is to wash out the phase transition for states with quantum numbers: $K = 1/2, 3/2, 5/2$ and to enhance it for states with $K = 7/2, 9/2, 11/2$.

An important property of atomic nuclei is that they provide experimental evidence for shape $QPTs$, in particular, of the spherical to axially-deformed transition $(U(5)-SU(3))$. One of three signatures has been used to experimentally verify the occurrence of shape phase transitions in nuclei, namely: the behavior of the gap between the ground state and the first excited 0^+ state.

The nucleus ^{152}Sm, with $N = 90$ and $Z = 62$, lies intermediate between nuclei of known spherical shape and well-deformed axially-symmetric rotor structure. A sudden

change in deformation occurs at $N \approx 88-90$ for the Sm and neighbouring isotopic chains, see Figure 6.

New data obtained in [31] constrains the description of this nucleus within the IBM to parameter values near the critical point of the transition from oscillator to rotor structure.

The performed IBA calculations in [31] for the entire region $N \approx 90$ with the simple IBA Hamiltonian which involves only one parameter, ξ which depends only on the neutron number N, for all the isotopic chains, are given in Figure 6, where is shown that the evolution of some basic observables in $Nd-Sm$ is very well reproduced by these calculations. The energy of the intrinsic excitation 0^+ has a minimum at the phase transition point. The phase/shape transition is mirrored in the calculations and, as noted, the IBA parameter ξ plays the role of a control parameter.

The total energy surface [31] corresponding to the Sm isotopes obtained from the IBA with increasing neutron number changes the location of the deformation minimum, from $\beta = 0$ to finite β when the neutron number increases from 88 to 92.

Notice that the bosons ($Z(62-50)/2=6; N(90-82)/2=4$) pairing appears for ${}^{152}_{62}Sm^{90}(stable) \leftarrow EC \leftarrow {}^{152}_{63}Eu^{89}$, and ${}^{150}_{62}Sm^{88}(stable) \leftarrow \beta^- \leftarrow {}^{150}_{61}Pm^{89}$, until a free proton appears for ${}^{151}_{62}Sm^{89} + \beta^- \rightarrow {}^{151}_{63}Eu^{88}(stable)$, and ${}^{153}_{62}Sm^{91} \rightarrow \beta^- \rightarrow {}^{153}_{63}Eu^{92}(stable); {}^{155}_{62}Sm^{93} \rightarrow \beta^- \rightarrow {}^{155}_{63}Eu^{92}$, the same situation for ${}^{147}_{60}Nd^{87} \rightarrow \beta^- \rightarrow {}^{147}_{61}Pm^{86} \rightarrow \beta^- \rightarrow {}^{147}_{62}Sm^{85}(stable)$, etc.

Now, in terms of our model defined interactions, it means that a proton is composed of 2 vortexes (V) and 1 antivortex (AV) of different spin, a neutron is a Giant-vortex (GV). Therefore, for $N \le 90$, we have an interaction $(V-V)-(V-AV)$, and above of $(V-AV)-(V-GV)$ type, respectively. Based on these rationales we have obtained the values of $E(0^+)$, as shown in Fig. 6, where, we show distinctly the values of interactions $(V-GV);(V-V);(AV-V)$ as calculated with equations (64-66).

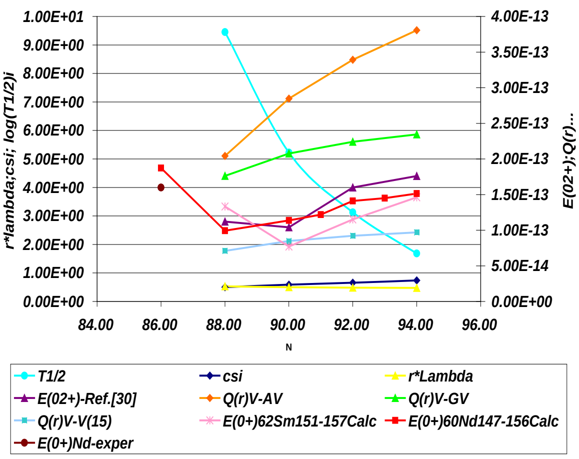

Fig. 6 The evolution of empirical values of $E(0_2^+)$ in the $Nd-Sm$ isotopic chains with $N > 82$ compared with the IBA results as extracted from [31], and of $E(r)$ as calculated by the present model

In both models the phase/shape changes , in our model, the phase slip which conducts to a dark count accompanied by a W boson energy depends on a single parameter $w = r \cdot \lambda$, till in IBA model are functions of a control parameter ξ and a quadrupole deformation β as an order parameter, respectively, see Fig. 6.

Our model has the advantage to explain the cause of phase change and its associated probability, as expressed by the inherently dark counts rate or the decay half-time $T_{1/2}$.

IV. CONCLUSIONS

A model was developed in which a photonuclear reaction is viewed as an incident photon creating superconducting hot spot (hot belt) across nucleon from the composition of a unstable nuclide (radioisotope), followed by a thermally induced vortex crossing, which turns superconducting hot belt into the normal state (vacuum) resulting in a vortex assisted photon beta decay. Because this model, firstly developed for superconducting nanowire single-photon detector (SNSPD), requires data on energies of vortex and on currents from inside of the nucleon, an analog of a superconductor model was developed for the nucleon.

Thus, a model G-L was revisited in order to calculate the Lorenz force, the current, and the energies of the Abrikosov vortex lines inside of the nucleon. It was found that these energies correspond to subatomic particles, W, Z, Higgs bosons, and of meson π. Therefore, the nucleon can be seen as a triangular lattice with three pairs of quarks-antiquarks in the tips of the triangle. These axial vortexes (filaments) interacting in the lateral plane.

All of the keys of this model, as being analogous to a superconductor clinging very well, starting with the use of Maxwell's equation with monopoles, further mass, charge, and the number of monopoles (density), which define the penetration depth and the coherence length could be considered as new fundamentals constants for nucleons. Also, we can say that, because no free quarks were detected, the same is true for monopoles, for both of which are confined together and in full in nucleons, when the temperature of the universe has reached $2*10^{12}\ {}^0K$.

Finally the model provides counts (decay) rates (R_{pc}) comparable with the experiments, and allows the estimation of intensity $R_h\left(photons/s\right)$, and of threshold value of photons energy (MeV), in order to achieve $R_{pc}/R_h \cong 1$, or (100%) efficiency of beta decay type radionuclides in the frame of the nuclear transmutation in the reducing of radioactive waste, together with α decay enhancement method. As a validation test, this is the application of this model to the mechanism of natural beta decay viewed as dark count rate, which was discussed in comparison with the results of nuclide substructure model IBA.

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